Mentha spicata - A Potential Cover crop for Tropical Conservation Agriculture

A thesis submitted to the Office of Graduate Education, University of Hawaiʻi at Mānoa in partial fulfillment of the requirements for the degree of

Master of Science in
Tropical Plant Pathology

November 4, 2016

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Acknowledgements

I thank Dr. Brent Sipes for being my chairperson along with his encouragement and guidance throughout my graduate study. I also thank Dr. Koon-Hui Wang and Dr. PingSun Leung for their time spent working with me and serving on my thesis committee. I appreciate and thank Donna Meyer and Mike Young for assistance with experiments in the laboratory. I also thank Dr. Uchida, Dr. Hu, and Dr. Alveraz who pushed my limits with obtaining information and for their availability outside of class. I especially thank my Mom and sister, Jacqueline, for being inspirational examples for my life, for their constant encouragement, and their support. I thank my laboratory mates Jin-Wah Lau, Justin Bisel, Lily Fatdal, and Abdul Al-Hussaini and peers Nikki Desonier, Natasha Navet, Shova Mishra, Shelby Ching, Philip Waisen, Josiah Marquez, DanDan Shao, Firas Ahmed, and James Green who worked with me as classmates and friends.

Abstract

Mint (*Mentha* sp.) is an important crop used raw or processed into oil for a variety of consumption purposes. This thesis evaluated mint for its potential to be a valuable living mulch in conservation agriculture-vegetable production. Furthermore, mint, as a living mulch, creates multiple benefits including reduction of soil erosion, reduction of water and nutrient runoff, retention of water, and reduction of weeds and pests. Mint susceptibility to plant-parasitic nematodes and the profitability of mint in a vegetable agro ecosystem have not been well studied. A greenhouse experiment was conducted to examine susceptibility of spearmint (*Mentha spicata)* and peppermint (*Mentha pepreti*) to root-knot *(Meloidogyne incognita, M. javanica)* and reniform *(Rotylenchulus. reniformis)* nemtodoes. Both mint species were not a host to *M. incognita*, *M. javanica,* nor *R. reniformis*. The nematode reproductive factors (Rf = final nematode population/initial nematodes population) after 2 months were all < 1.0 for these nematodes on mint. A micro-plot field experiment was conducted to examine the effect of spearmint living mulch eggplant vegetable system compared to a bare ground eggplant vegetable system. The spearmint living mulch did not affect eggplant yield throughout the 14 months of the experiment as compared to the bare ground system. After the initial year of establishment, additional profit from harvesting spearmint for sale was estimated to be $20,949.06 per hectare annually based on a partial budget economic analysis. Planting spearmint as a living mulch in an eggplant agro ecosystem provides an economically viable conservation agricultural production system in a water resourceful environment.

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Chapter 1: Introduction

Mentha

Mentha, commonly called mint, is a genus in the Lamiacae. The genus consists of 25–30 species (Ali et al., 2002). Many varieties of mint exist and the cultivars selected for commercial production are generally specific to a geographic area. In the eastern hemisphere the most common species grown and studied is *M. arvensis* (Kumar et al., 2000). *Mentha arvensis* is commonly called field mint, wild mint, corn mint, or Japanese mint (Singh et al., 2005). *Mentha spicata*, spearmint, and *M. pepreti*, peppermint, are the most common species cultivated in the western hemisphere (Ullah et al., 2012). Spearmint and peppermint are economic crops that are used raw or processed into oil for a variety of consumption purposes.

In the United States, spearmint and peppermint are produced commercially in California, Idaho, Indiana, Michigan, Oregon and Washington (Table1). Although mint grows the best in partially shaded, cool, moist areas (Bradley, 1992), it can be grow in a wide range of environments when provide water. Mint tolerates many climates, growing throughout areas of Europe, Asia, North America, Australia and Africa (Brickell and Zuk, 1997). Mint is propagated by division or from cuttings. Most mint producers harvest 3-4 years before replanting. Mint is harvested for fresh consumption and for processing. Mint hay is mown and dried for several days before being collected for distilling. Mint oil is extracted by steam at distilleries located not far from the mint production areas (www.rma.usda.gov/pilots/feasible/PDF/ mint.pdf). Once oil is extracted, dealers create different oil blends for manufactures (www.rma.usda.gov/pilots/feasible/PDF/mint.pdf). Mint oil is valued at about $10/454g 20-fold more valuable than soybean oil (www.nass.usda).

Table 1.1. Production of spearmint and peppermint oil in the United States in 2015.

State	Peppermint Area harvested (ha)	Peppermint Production (kg)	Spearmint Area harvested (ha)	Spearmint Production (kg)
California	768	70,760	na*	na
Idaho	6,151	723,933	526	85,729
Indiana	404	181,436	1,416	85,729
Michigan	-	-	na	na
Oregon	8,498	904,916	1,011	153,314
Washington	5,665	698,532	7,243	1,006,067
Other States	1,254	88,450	809	61,688
Total US	26,385	2,668,030	9,874	1,392,528

* na = data not available

Mint has medicinal and culinary uses. In the past, beneficial attributes and uses of the raw mint and mint oil have been passed down through tradition or folklore (Pirbalouti et al., 2010). Fresh mint provides aroma and flavor to many foods (Park et al., 2002). Mint is used in salads, chutneys, garnishes and dips. Mint flowers, stems and leaves are commonly used to make herbal tea (Kothari and Singh, 1995; Moreno et al., 2002). Liqueurs and candies are also flavored with mint. Dried mint is an additive in commercial spice blends (Kothari and Singh, 1995; Moreno et al., 2002). Mint has historically been used as an anti-inflammatory, a carminative, an antiemetic, and a diaphoretic. Traditionally, mint has been prescribed as a treatment for flatulence, nausea, bronchitis, anorexia, and colitis (McKay and Blumberg, 2006). Mint also is used a gastric stimulate (Budavari et al., 1989; Gupta, 1991) and an antispasmodic (Iscan et al., 2002). Mint oil is widely used as a component of commercial medicines such as cough drops and cough syrups (Kor, 2015). Mint oil can be used as a topical analgesic for muscle aches, cramps, arthritis, tendinitis and sprains. Mint oil is an antipruritic and can treat mosquito bites (Khanzada, 2012) and poison ivy (Kor, 2015). Cosmetically mint is used for aromatherapy (Herro and Jacob, 2010). Mint is added to products to lend scent and enhance fragrance (Herro and Jacob, 2010). Mint is widely used in beauty products and is added to shampoos, lotions, and balms. Mint is also added to some cigarettes to lessen the bitterness of tobacco (Khanzada, 2012). Mint oil has also been shown to be an environmentally safe insecticide (Nerio et. al, 2010.).

Living Mulches

Living mulches provide benefits over and above those associated with cover crops or green manures. Living mulches are cover crops planted either with or before a main crop and then maintained throughout the growing season. Living mulches protect water quantity, quality and help maintain soil moisture (Morse, 1993). If the living mulch is perennial, there is no need for reseeding (Hartwig, 1983; Hartwig, 1987). Proven living mulch systems include planting legumes to reduce nitrogen inputs during the growing season. Hairy vetch provides a significant amount of nitrogen to the soil (Decker et al., 1994). Living mulches control and prevent problematic weeds (Hartwig, 1977; Hartwig, 1989). White clover provided better weed control than a commercial herbicide in sweet corn and snap bean (DeGregorio and Ashley, 1985; DeGregorio and Ashley, 1986). Winter rye, ryegrasses, and subterranean clover are living mulches that are allelopathic to or out compete small-seeded weeds (Else and Ilnicki, 1989), thus when used as a living mulch, they reduce the need of herbicides. Living reduce surface water runoff, mitigate nutrient leaching (Staver and Brinsfield, 1998; Dinnes et al., 2002), and reduce pesticide use (Hall et al., 1984; Ruttimann, 2001). Protecting the soil from water runoff reduces soil erosion (Langdale et al., 1991). A living mulch of crown vetch with corn reduced water and pesticide runoff with insignificant of soil loss (Hall et al., 1984). Living mulches improve the structure of the soil. Plant residues break down and create aeration and encourage root growth, increased soil fertility, and improved soil productivity (Cavigelli, 2003). A living mulch with a vigorous root system can lessen soil compaction and improve the structure of over-tilled soil (Kemper, 1980; Creamer et al., 1996). Some living mulches can even decrease insect pests by producing flowers that attract beneficial insects and suppress plant diseases (Sustainable Agriculture Network, 1998)

Mentha spp. has potential as a living mulch in small landholder tropical agriculture. Mint can serve as a companion plant, acting as a wind break, increasing yields by encouraging companion plant growth, decreasing pest pressure by attracting beneficial organisms or suppressing pest directly. Mint has been plant with bell peppers, tomatoes and broccoli. Mint has fast spreading runners that allow it to grow aggressively (Kumar et al., 2011). These runners grow fine fibrous roots, which are ideal in preventing soil erosion from wind and rain. Mint's roots spread and leave cover soil lessening the impact of rain contributing to less water runoff and increased soil moisture retention. The roots of mint also loosen the compaction of over-tilled soil. Mint plants deter ants as well as mosquitoes (Khanzada, 2012). While not suppressing weeds on its own, mint can be established to dominate and take over the field, thus reducing need for chemical weed control. and heavy rainfall. The many uses of mint potentially allow for quicker monetary benefit for the farmer when mint is used as a living mulch.

Profitability of Living Mulches

Little research has been undertaken to evaluate the role of mint as a living mulch in a vegetable cropping system. Before changing an operating method in production a farmer needs to know the economic benefit of having a living mulch (Alimi and Manyong, 2000). A straight forward and valuable method to evaluate any innovative change in farm level production practices is partial budgeting. Partial budgeting evaluates aspects of operating that are able to be adjusted (Dalsted and Gutierrez, 1990). Using partial budgeting allows determination of the change in income and the level of profitability based on costs of inputs and market price of crops (Alimi and Manyong, 2000).

Due to the multiple usage of mint for human consumption, this thesis proposes to intercrop mint with cash crop as a living mulch. Mint brings in additional income for the small landholder farmer when grown as a companion crop. Mint can be harvested and be sold raw, processed for oil, or added into other products. However, little scientific research is available on use of mint as a living mulch.

Tropical Plant-Parasitic Nematodes

As a perennial living mulch, the host status of mint to tropical plant-parasitic nematodes is important. In the tropics and subtropics, plant-parasitic nematodes cause an estimated yield loss of 17 to 20% annually (Sasser, 1979). Mint is a host to a range of temperate plant-parasitic nematodes including *Criconemella xenoplax* (Merrifield and Ingham, 1996), *Longidorus elongates* (Jatala and Jensen, 1974), *Meloidogyne hapla* (Eshtiaghi, 1975*), Paratylenchu*s sp. (Faulkner, 1964), *Pratylenchus neglectus* (Kleynhans et al., 1996), *P. penetrans* (Ingham and Merrifield, 1996), *P. thornei* (Ingham, pers. comm.). However, the host status of mint to the most damaging and wide spread plant-parasitic nematodes in the tropics, *M. incognita, M. javanica* and *Rotylenchulus reniformis*, is unknown. Susceptibility of mint to these tropical nematode species needs to be evaluated before recommending mint as a living mulch.

Objective of the Thesis

The objective of this research is to evaluate spearmint and peppermint as potential living mulch for use in small landholder vegetable production systems in tropical areas. The specific objectives are to:

1) Evaluate spearmint and peppermint susceptibility to *M. incognita, M. javanica* and *R. reniformis;*
2) Determine the effect of *M. spicata* as a living mulch in tropical small landholder eggplant vegetable production; and
3) Evaluate the profitability of mint production when intercropped as a living mulch with eggplant.

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Chapter 2: Spearmint and Peppermint Susceptibility to Root-knot and Reniform Nematodes

Peppermint and spearmint are important fresh and oil crops grown around the temperate world. In the United States, peppermint and spearmint were traditionally grown above the 41st parallel in areas with long days (Burbott and Loomis, 1967; Langston and Leopold, 1954). Much of this production was for the extraction of oil. With increases in demand, mint cultivation has expanded into additional geographic areas. Research and commercial production demonstrates that peppermint and spearmint can be successfully produced below the 41st parallel with shorter day lengths (Lawrence, 2007). In the south eastern United States, mint is grown for its fresh and dry leaves into addition to oil (Zheljazkov et al., 2010a; Zheljazkov et al., 2010b). Fresh and dried leaves are used for teas and to give flavor to foods and beverages. The impact of pests found in a geographic area should be considered when evaluating innovative crops and practices for that area. Mint is no exception.

Several plant-parasitic nematodes are associated with mint grown in temperate regions, such as *Meloidogyne hapla*, *Pratylenchus,* and *Paratylenchus* (Ingham and Merrifield, 1996). However, other plant-parasitic nematodes are found in tropical and subtropical agroecosystems. *Meloidogyne incognita*, *M. javanica* and *Rotylenchulus reniformis* are plant-parasitic nematodes are found in tropical climates that generally are not found in temperate agricultural fields (Luc et al., 2005). Definitive research on whether spearmint and peppermint are hosts for these tropical plant-parasitic nematodes does not exist. To evaluate the potential production of spearmint and peppermint in tropical and subtropical agricultural production systems, the susceptibility of spearmint and peppermint is important to know. The objective of this experiment was to evaluate the susceptibility of spearmint and peppermint to three common plant-parasitic nematodes in Hawaii, *M. incognita*, *M. javanica* and *R. reniformis*.

Materials and Methods

Two greenhouse trials were undertaken to determine the host status of spearmint (M*entha spicata*) and peppermint (*Mentha piperita*) for *M. incognita*, *M. javanica* and *R. reniformis*. Nematode inoculum was collected from cultures of *M. incognita* and *M. javanica* maintained on *Solanum lycopersicum* 'Orange Pixie'. *Rotylenchulus. reniformis* inoculum was collected from cultures maintained on *Vigna unguiculata*. Nematode eggs of each species were extracted from the roots of 3-month old cultures by washing the soil from the roots. The roots were then shaken in a 5% NaOCl solution for 4 minutes (Hussey and Barker, 1973). The solution was poured through a 0.002 µm pore sieve, thoroughly rinsed with tap water, and then transferred into a centrifuge tube. The eggs were pelleted and the water decanted. The eggs were resuspended in a 38.5% sucrose solution and centrifuged for 1 minute. The eggs were collected on a 0.002 µm pore screen and rinsed with tap water. Eggs were counted and adjusted to 500/ml for *M. incognita* and *M. javanica*, and 350/ml for *R. reniformis*. Eggs were stored at room temperature until ready for soil inoculation.

Spearmint and peppermint plants were prepared by taking 2-3 cm long cuttings from stock plants. The cuttings were placed in seedling trays filled with a sterile sand and soil mix. The trays were placed in the greenhouse and allowed to root for 2 months (Fig. 2.1). Two months later, the rooted cuttings were transplanted into 20- ml disposable paper pots. The plants were separated into 4 sets of 10 plants each. Each pot was inoculated with 500 eggs of *M. incognita* or *M. javanica* eggs, 350 eggs of *R. reniformis*, or treated with 1 ml of water (control). Pots were organized in a complete randomized design on the greenhouse bench (Fig. 2.2).

Figure 2.1. Spearmint and peppermint cuttings rooting in seedling trays in a greenhouse.

Figure 2.2. Pots of spearmint and peppermint in a randomized design on a greenhouse bench.

Two months after inoculation, plants were harvested and nematode reproduction determined. Shoot and root fresh weight were recorded. Nematode eggs were extracted from each plant using the NaOCl shaking method followed by centrifugal floatation method as described earlier (Jenkins, 1964; Hussey Barker, 1973). Eggs from each pot were collected and counted with the aid of an inverted microscope. The shoots and roots were oven dried to a constant weight.

The experiment was repeated with 2 month-old spearmint and peppermint propagated from cuttings. In this repeat, each pot was inoculated with 425 eggs of *M. javanica*, 710 eggs of *R. reniformis*, or treated with 1 ml water (control). Pots were arranged in a complete randomized design with 10 replications. The experiment was terminated 2 months after nematode inoculation as described in the first repeat.

Statistical analysis was conducted using SAS 9.4. Prior to analysis of variance (ANOVA), data were tested for normality using Proc Univariate. Nematode egg data were log-transformed (Log10 (x+1)). Effects of nematode on the two mint shoot, root, and total fresh weight were compared. A nematode reproductive factor (Rf = Pf/Pi) was calculated where Pf was the number of eggs recovered from a pot and Pi was the level of inoculation. The Rf for each nematode was subjected to one-way ANOVA by mint species. Means of nematode treatments were separated using Waller-Duncan *k*-ratio (*k* =100) *t*-test.

Results

Nematode infection did not adversely affect mint growth. In the first repeat, the dry and fresh root weights and the fresh shoots along with the total fresh weight were not different (P>.05) between the inoculated and uninoculated spearmint or peppermint plants (Table 2.1). In second repeat, the plants did not grow as much as in the first repeat. The fresh root and total

Table 2.1. Fresh weights (g) of spearmint and peppermint roots, shoots, and total as affected by different nematodes mean weight (g) in two trials.

Nematode	Spearmint			Peppermint		
	Fresh root	Fresh shoot	Total	Fresh root	Fresh shoot	Total
			Trial 1			
Uninoculated	7.45	8.32	15.77	3.28	8.94	12.22
Meloidogyne incognita	6.02	9.19	15.21	3.02	8.94	11.97
Meloidogyne javanica	5.86	9.06	14.91	3.70	9.70	13.41
Rotylenchulus renifomis	5.92	10.99	16.92	3.38	9.48	12.87
			Trial 2			
Uninoculated	1.81	1.30	3.11	2.18	2.16	4.34
Meloidogyne javanica	2.18	1.11	3.29	1.73	3.21	4.94
Rotylenchulus renifomis	2.55	1.57	4.13	2.38	1.46	3.84

fresh weight of spearmint were higher under inoculation with *R. reniformis* in the second repeat. Peppermint fresh shoot weight was greater in those plants inoculated with *M. javanica* whereas fresh root weight of plants inoculated with *M. javanica* was lower than the uninoculated plants in the second repeat (Table 2.1). Spearmint fresh shoot weight was not affected by interaction of treatments while fresh shoot weight was reduced with the peppermint and *R. reniformis* interaction.

Neither spearmint nor peppermint were hosts to any of the nematodes tested. The nematodes reproduced at a very low levels in spearmint and peppermint. For trial 1, on spearmint, *M. incognita* produced 7 eggs/plant, *M. javanica* 1 egg/plant, and *R. reniformis* produced 189 eggs/plant. On peppermint, 6, 7, and 14 eggs/plant were produced by *M. incognita*, *M. javanica*, and *R. reniformis* respectively. And for trial 2, on spearmint, *M. javanica* produced 2 eggs/plant, and *R. reniformis* produced 17 eggs/plant. On peppermint, 3, and 8 eggs/plant were produced by *M. javanica*, and *R. reniformis* respectively. All these Pfs were lower than inoculation level. Consequently, the Rf was less than 1 for all nematodes on both mints (Table 2.2).

Discussion

Overall, *M. incognita*, *M. javanica* and *R. reniformis* did not negatively impact spearmint or peppermint growth. The low inoculation densities of *M. javanica*, and *R. reniformis* used in the trials may have stimulated growth on peppermint and spearmint, respectively. Neither spearmint nor peppermint were hosts to *M. javanica, M. incognita*, or *R. reniformis.*

These results are very encouraging. Recommendations to use mint as a living mulch in vegetable crops such as eggplant, tomato, trellis-grown cucumber or corn would be appropriate. Utilizing mint as a perennial ground cover in vegetable crops would be compatible with conservation agricultural practices promoted by the United Nation, Food and Agriculture Organization (FAO) which entails three farming principles: 1) minimal soil disturbance; 2) continuous soil cover; and 3) crop rotation (FAO, 2015). Since mint would serve as perennial cover in these vegetable systems, minimal tillage would only be conducted on the cash crop planting row. This type of conservation agriculture should be manageable for smallholder vegetable product in tropical areas.

Many vegetable crops are susceptible to *M. incognita*, *M. javanica* (Sasser, 1979) and *R. reniformis* (Linford and Oliveira, 1940). Since spearmint and peppermint are not hosts to these plant-parasitic nematodes, a future experiment to investigate the effect of a mint ground cover on nematode infection of a susceptible vegetable would be most interesting. It is possible that the mint ground cover could help to manage the nematode population and damage on the vegetable crop.

Table 2.2. Reproductive factors (Rf) of root-knot and reniform nematodes on spearmint and peppermint grown in the greenhouse in two trials. No value is significantly different from 0 ($P>0.01$).

	Rf Trial 1		Rf Trial 2	
Nematode	Spearmint	Peppermint	Spearmint	Peppermint
Meloidogyne incognita	0.01	0.01	NA	NA
Meloidogyne javanaica	0.02	0.01	0.01	0.01
Rotylenchulus reniformis	0.54	0.04	0.02	0.01

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Chapter 3: Intercropping Spearmint with Eggplant in the Tropics

Introduction

Spearmint (*Mentha spicata*) has potential for use as a living mulch in smallholder tropical vegetable crop production. Several characteristics warrant spearmint's evaluation as a potential living mulch. Spearmint aggressively spreads by runners and produces fine adventitious roots that allow establishment of a good ground cover (Kumar et al., 2011). Spearmint forms a thick thatch ground cover. The leaves of the plant reduce the direct impact of raindrops on the ground which is ideal for reduction of soil erosion and protection of the soil structure. Spearmint roots uptake excess water while contributing to less water runoff and increasing soil moisture retention. As a living mulch, spearmint plants have effects on some pests. Mint deters ants as well as mosquitoes (Khanzada, 2012). Mint will also act as an insectary plant and attract beneficial insects. Once established, mint outcompetes weeds which reduces the need for chemical weed control (Dhima et al., 2009). Corsican mint (*M. requiennii*) in a mixed-herb orchid ground cover increased soil organic C and N by 32% and 47% within 2 years, respectively (Hoagland et al., 2008).

The benefits of mints in a cropping system suggest that mint may also benefit management of soil borne pests as well as enhance soil and plant health. Soil health is the capacity of a soil to function within its ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health (Wang and McSorley, 2005). The benefits of mint as a living mulch for soil health improvement is justifiable. None-the-less, there is a dearth of knowledge on whether using mint as living mulch could improve soil health.

As a living mulch, spearmint provides benefits in addition to its ecosystem services. Spearmint is an agricultural product providing fresh material and oil when processed. When harvested, spearmint living mulch can be sold to restaurants, stores, and at markets to provide additional income for farmers. The objective of this research is to evaluate spearmint as living mulch in an eggplant tropical. The specific objectives were to determine the effect of a spearmint living mulch on 1) plant-parasitic nematode populations; 2) eggplant yield, and 3) soil health.

Materials and Methods

Spearmint transplants were propagated by taking 2-3 cm long cuttings from stock plants. The cuttings were placed in seedling trays filled with a 1:1 sterile sand and soil mix. The trays were placed in the greenhouse for 2 months prior to field transplanting in the field. Once rooted, the spearmint was transplanted into the field plots.

Eggplant (*Solanum melongena* ‘Waimanalo Long’) seeds were germinated in a community pot filled with vermiculite. Upon appearance of the first true leaves, the seedlings were transferred into individual 500-ml paper pots filled with a sterile 1:1 soil sand mix. When the eggplant seedlings were 10 cm tall, they were transplanted into the field plots.

A field plot was established at the University of Hawaii Magoon Facility in Manoa, Honolulu. The plot, fallowed with weeds, was rotor-tilled twice, prior to establishing the experiment. Six 4 m × 3 m plots of were established in the field. Two drip irrigation lines were placed in each plot. Plots were randomly assigned to the bare ground or spearmint living mulch treatments (Fig. 3.1). Spearmint seedlings were transplanted into appropriate plots on a 30 × 30 cm grid spacing. Two months later when the spearmint living mulch had covered the plot, eggplants were transplanted. Each plot contained 8 eggplants with 4 plants in a row 2 cm from the irrigation line with 50 cm between plants. The eggplants were fertilized at transplanting, 3

Figure 3.1. Diagram of spearmint and bare ground plots (3m x 4m) of a field at the University of Hawaii Magoon facility.

weeks after planting, and monthly thereafter with labeled rate of MiracleGro fertilizer (Scotts Company, Marysville, OH). Spearmint was fertilized monthly also. Irrigation needs were determined by weather and soil conditions to provide 1-acre inch of water a week. Beginning at 4 months after eggplant transplanting, fruits were harvested and weighed from each plot weekly. The number of fruit per plot and the total weight of fruit per plot were recorded. Fruit harvest data were accumulated from each plot over a 10-month period. Six months after eggplant transplanting, spearmint foliage was harvested. Spearmint was cut 30 cm above the ground every 3 months thereafter. The fresh shoot weight of the cut spearmint was recorded.

Soil samples were collected from each plot at 4-month intervals and extracted for nematodes. A 10-cm deep soil core was collected systematically from 5 spots in each plot away from the eggplant rhizosphere. The soil was composited and nematodes from a 250 cm^3 subsample were extracted elutriator (Byrd *et. al*, 1976) and centrifugation (Jenkins, 1964). With the aid of an inverted microscope, the plant-parasitic nematodes were identified and counted. Free-living nematodes were counted.

Eggplant yield was subjected to one-way analysis of variance (ANOVA) by month using Proc GLM in SAS (SAS Inc, Cory, NC). Based on homogeneity of variance test using Proc Univariate in SAS, nematode counts were log-transformed log10(x+1) to normalize the data. Nematode data were then analyzed by 4 × 2 (sampling time × treatment) ANOVA. When sampling time interacted significantly with treatments, data were analyzed by sampling date using Proc GLM.

Results and Discussion

Total cumulative eggplant yield was not affected by the spearmint living mulch throughout the cropping season ($P > 0.05$). Yield did not differ among the bare ground and living mulch except in the fourth month harvest (February 2016) when eggplant yield was higher in the spearmint living mulch compared to the bare ground plots ($P \leq 0.05$, Fig. 3.2). The total eggplant yield over the 10 months was 112.70 kg/plot in the bare ground and 127.18 kg/plot in

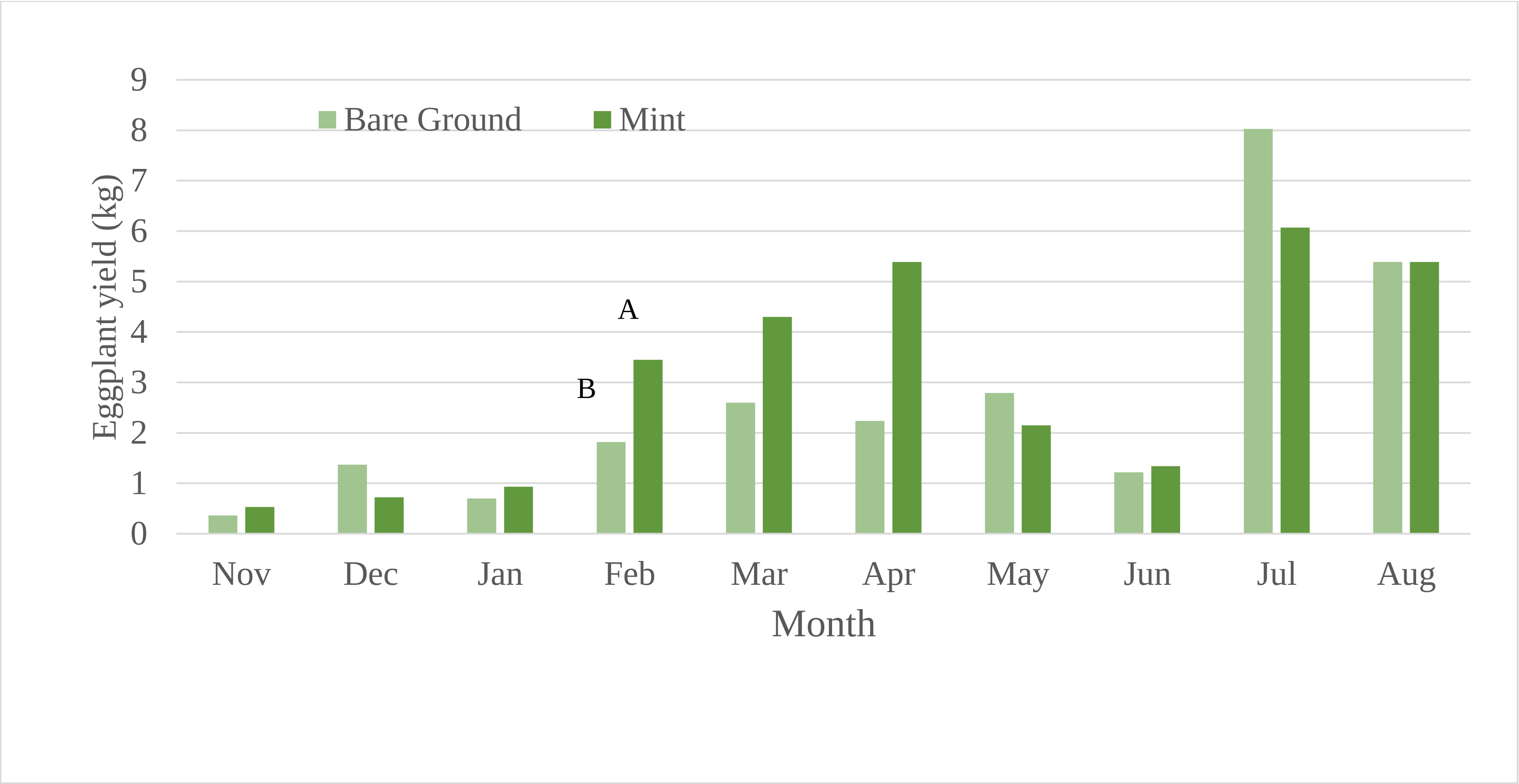

Figure 3.2. Yield of Waimanalo Long eggplant grown under bare ground or a spearmint living mulch. Eggplant harvest data are averages from weekly totals from three replicated plots. Bars in a month with the same letter are not different (P>0.05).

the mint plots. Season had an effect on eggplant yield. Yields were lower in November than in June (Fig. 3.2). The cooler weather was less favorable for eggplant production. Intercropping eggplant with a spearmint living mulch had no effect on eggplant productivity. Spearmint production was successful in the eggplant-mint living mulch treatment. Spearmint yield was slightly different with each harvest depending on the season but average yields did not differ among the three harvests ($P>0.05$). It took 6 months to establish the field of mint, so the first year had only two harvests. The harvests equaled 16.39 kg/36m^2 which is equivalent to 4,552.81kg/ha. Spearmint is perennial, so after the first year of establishment it can be harvested 4 times per year. In this experiment spearmint yielded an averaged of 8.57 kg/36m^2 (Fig. 3.3) for 1 harvest. this is is equivalent to 9522.30 kg/ha annually. The spearmint harvest can increase revenue for the farmer in addition to the other benefits of the living mulch.

Only two genera of plant-parasitic nematodes were recovered in the plots. *Rotylenchulus reniformis* and *Helicotylenchus* sp. were recovered at the start of the experiment (Table 3.1). The spearmint living mulch did not increased the abundance of either species of plant-parasitic nematode during the course of the experiment (Table 3.1). The abundance of the free-living nematodes increased over time in both plots. The abundance of free-living nematodes was higher in the spearmint living mulch than in the bare ground.

A living mulch of spearmint proved to be very successful for a vegetable cropping system. The living mulch enhances the maintenance of soil moisture and minimized soil erosion. The living mulch was increasing the biological diversity of the soil as evidenced by an increase in the population of free-living nematodes. Additionally, the spearmint living mulch did not affect the yield of the eggplant cash crop. Furthermore, spearmint as a living mulch provided positive economic potential as a valuable crop in itself. Mint living mulches are worthy of

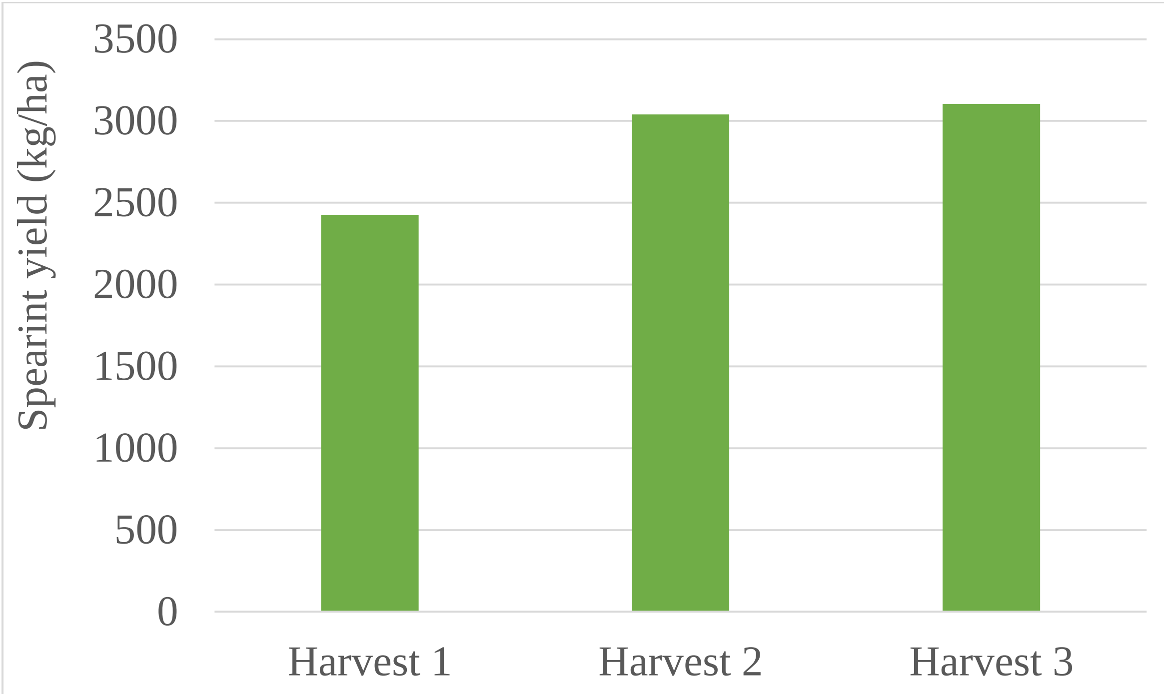

Figure 3.3. Spearmint yield (kg/ha) over three harvests in an eggplant-spearmint living mulch vegetable system. Yields do not differ among the harvest dates (P>0.05).

Table 3.1. Nematode soil population densities (per 250 cm^3 soil) over time in an eggplant cropping system maintained as bare ground or as a spearmint living mulch. Numbers are averages of 3 composite samples.

Treatment	Nematode		
	Helicotylenchus	*Rotylenchulus*	Free-living
At spearmint establishment (July 2015)			
Bare ground	130	0	0
Living mulch	0	630	0
3 months after eggplant (November 2015)			
Bare ground	30	100	0
Living mulch	1300	1400	0
7 months after eggplant (March 2016)			
Bare ground	0	60	90
Living mulch	660	380	120
11 months after eggplant (July 2016)			
Bare ground	140	270	770
Living mulch	70	90	1460

additional investigation with other appropriate vegetable crops to ensure that the benefits occur across vegetables.

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Chapter 4: Profitability of Intercropping *Mentha spicata* and *Solanum melongena*

Introduction

A living mulch is a cover crop that is interplanted with the cash crop and provides services such as reduction of soil erosion, retention of moisture and nutrients, pest suppression and enhanced soil food webs. Often the living mulch provides no additional income, other than the contribution of beneficial environmental services to the cash crop. Intercropping, on the other hand, is the cultivation of two harvestable crops on the same plot of land (Willey and Osiru, 1972; Ofori and Stern, 1987; Willey 1979). A living mulch and an intercrop are not mutually exclusive. Appropriate selection of plant to act as both a living mulch and an intercrop is possible. Spearmint is one such example. Spearmint has proven to be an appropriate living mulch in an eggplant vegetable cropping system (Chan, 2016) and the spearmint can be cut and harvested as an intercrop with the eggplant. This eggplant spearmint living mulch system has added costs to the grower but provides additional income to the grower as well.

Partial budgeting as an effective means to evaluate changes in a production system that do not require complete reorganization of the farm (Dalsted and Gutierrez, 1990). Partial budgeting evaluates small changes in the farm. Partial budgeting is applicable for expansion of an enterprise, changing production practices, hiring additional labor or purchasing new equipment. These changes can reduce cost, reduce returns, add cost or add returns to the farm enterprise. The net effect will assist the farmer in making decisions on the changes that are being considered.

Partial budgeting does not take into account existing fixed resources. For the case of this eggplant spearmint living mulch study, existing fixed resources include those things used to produce the eggplant including land, water, greenhouses, equipment and transportation. The land used for intercropping the spearmint is existing space between the eggplant rows and between eggplant in a row that was previously unused. The land preparation, including weeding, was conducted for the eggplant production and was sufficient for the spearmint as well. The cultivation of the spearmint living mulch used the same amount of irrigation as was used for the eggplant alone. No extra equipment or transportation was required, as the farm had these for production of eggplant. Nothing additional was needed for the spearmint living mulch, except cost of seed and labor. The spearmint living mulch did not reduce the yield of eggplant (Chan, 2016).

The objective of this study was to determine a partial budget for a spearmint living mulch harvested as an intercrop in an eggplant vegetable production system. Two partial budgets analyses will be done. The first analysis will be done for the first year only. Spearmint is a perennial crop and may last up to 15 years once established (www.rma.usda.gov/pilots/feasible/PDF/mint.pdf), so propagation, planting labor as well as weeding costs will be a factor only here. The second analysis will be for up to 15 years following the initial year of establishment.

Materials and Methods

The economic profitability of spearmint as a living mulch in an eggplant agro ecosystem was analyzed based on data from a field experiment conducted at Magoon Teaching Facility, University of Hawaii, Manoa, Honolulu form July 2015 to June 2016 using partial budgeting (CIMMYT 1988). Hawaii crop budget templates for avocado and ginger were used as guides wherever applicable. Production and operating costs and yield of the eggplant spearmint living mulch experiment were recorded. Spearmint production was estimated using the sale price and cost from a commercial farm on Oahu. The commercial farm sale price is 13.02/kg and the cost is 11/kg. The experimental data was generated from small plots and was scaled to 1 hectare for analysis.

The first partial budget analysis is for the first year when the mint is being established. Propagation, planting and production costs are evaluated along with the first 2 mint harvests taken 3 months apart. Propagation and transplanting labor and weeding is estimated to cost \$48.50 for 300 mint transplants and planting and weeding labor. Costs for production were based on harvest yield, fertilizing, washing and packing labor costs, along with fertilizer, bag/box costs as well as accounting came to \$148.50. So the mint yield for this first year of establishment total cost was \$197 for 16.39kg. Adjusted for a hectare it is equivalent to \$5,283.43 for 4552.81kg annually. The second partial budget analysis does not include the propagation, planting and weeding costs but does include the same production costs and yield is harvested 4 times per year. The yield of spearmint during this experiment for 3 harvests averaged 8.57 kg/36m^2 with a cost of \$94.27 for 1 harvest. The adjusted yield annual yield, (4 harvests) was 9,522.30 kg fresh mint for \$104,745.28.The expected income, costs, and yield of a spearmint living mulch intercrop was compared with the expected reduction in income, additional costs, and reduced yield from a spearmint living mulch system. A best case, competitive case, and worst case scenario were calculated using plus or minus 5% of price, costs, and yield. In order to assess profitability the following equations are used:

Profit of mint/hectare = (\$Total Revenue - Total Costs)/ha   Eq. 1

Total Revenue/hectare = Total Yield (kgs/ha) * \$Price/kg   Eq. 2

Total Costs/hectare = $\sum$ (Cost of Inputs prior to each harvest)/ha Eq. 3

Results

The profit from intercropping eggplant with a spearmint living mulch was evaluated using two partial budget analysis, one for the first year of establishment and the second for the years after establishment. The reason the the second analysis is because spearmint is perennial and only needs to be propagated and planted once in 15 years. Therefore, the second analysis is more representative of the overall profit.

In the first year of establishment from intercropping eggplant with a spearmint living mulch there is profit of $5,283.42, a 9% profit margin (Table 4.1). After the first year of establishment the profit was $$20,949.06/ha or a 17% profit margin (Table 4.2) annually. This profit does not include the cost of operating and production that is already in place for producing and selling eggplant.

The sensitivity scenarios evaluated from the years following establishment included a best case, competitive case, and worst case. The base case was the expected profit, = $20,949.06, a 17% profit margin. The best case was when the price of spearmint increases by 5%. In the best case, a profit of $27,233.77 was generated, a 30% increase from base profit. For the competitive case, the spearmint price and yield was assumed to remain constant while costs decrease by 5%. The competitive case gave a $25,995.88 profit or a 24% increase from the base profit. In the worst case, the price of spearmint was assumed to decrease by 5% and costs were assumed to increase by 5%. Even in this scenario, a $9,236.63 profit, a 56% decrease from the base profit, results.

Table 4.1. A partial budget analysis for intercropping eggplant with a spearmint living mulch during the first year – or crop establishment. Production costs were determined from a small scale experiment and from a commercial farm.

Partial Budget Proposed change: Addition of spearmint as a living mulch intercrop			
Positive Change		Negative Change	
Additional income	Value	Reduced income	Value
Revenue from fresh spearmint	$60,097.14	None	$0
Reduced costs	Value	Additional costs	Value
None	$0	Extra production costs	$54,813.72
Total positive change	$60,097.14	Total negative change	$54,813.72
Total Change = Total positive change – Total negative change = $5,283.42			

Table 4.2. A partial budget analysis for intercropping eggplant with a spearmint living mulch after crop establishment. Production costs were determined from a small scale experiment and from a commercial farm.

Partial Budget Proposed change: Addition of spearmint as a living mulch intercrop			
Positive Change		Negative Change	
Additional income	Value	Reduced income	Value
Revenue from fresh spearmint	$125,694.34	None	$0
Reduced costs	Value	Additional costs	Value
None	$0	Extra production costs	$104,745.28
Total positive change	$125,694.34	Total negative change	$104,745.28
Total Change = Total positive change – Total negative change = $20,949.06			

Discussion

Because a spearmint living mulch with eggplant does not affect the yield of eggplant, harvesting the spearmint as an intercrop is potentially very profitable. And selling to the fresh market, spearmint can be harvested at any growth phase. A farmer does not have to harvest at set times and suffer lose from over harvested product. The simultaneous eggplant and spearmint production provides the farmer two products to sell. The added returns in both second partial budget analysis, shows intercropping with spearmint outweighs the added cost of the living mulch and therefore is profitable. Other benefits from the spearmint living mulch, in addition to the monetary returns from intercropping, such as weed reduction, pest suppression, water retention, and soil improvement are not economically accounted for. The contribution of the spearmint living mulch to the ecosystem will be in addition to those from the harvesting and selling of the mint. It is obviously that eggplant farmers would receive multiple benefits and should adopt a spearmint living mulch intercropping production system.

The sensitivity analysis demonstrated that profit is more sensitive to the same % change in price or yield than total costs. The important point perhaps is that any change in either price, costs, or yield can increase or decrease profits. Sensitivity analysis shows that aiming for a high price or boosting yield is the best way to increase profits for eggplant-spearmint production. Most importantly, even in the worst case scenario, the farm would still profit from intercropping eggplant with spearmint. Providing this profit estimation to farmers would provide more incentives for farmers to consider growing spearmint as a living mulch. A common stereotype of farmer opinion when recommending a living mulch for vegetable crop production is costs of labor and profitability. This economic analysis not only demonstrates that farmers could make additional profit despite the additional labor and input costs associated with spearmint. Spearmint is a high value crop and a good market niche crop in Hawaii that is worth to explore.

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Appendix

Partial budget analysis for intercropping a spearmint living mulch in an eggplant vegetable production system 1st yr. of establishment). . Labor is calculated at $8.50/hour. Fertilizer is $10/2.5 kg. Packing supplies are $1.50/25 boxes.

Partial Budget (year of establishment)					
			Study Data		
	Unit (2 harvests)				
Total Revenue	Total Revenue	Per 36m2	Per ha	1st year
Yield (kg)	Yield	16.39	4552.81	4552.81
Price ($)/kg	Price	13.20	13.20	13.20
Total Revenue ($)	Total Revenue	216.35	6,0097.14	6,0097.14
Seed	300	23.00	6,480.00	6,480.00
Transplant	1 hour		2,361.13	2,361.13
Weeding labor	2 hours	17.00	4,722.26	4,722.26
Fertilizer	250 g	1.00	4,722.26	277.78
Fertilize Labor	1 hour	8.50	2,361.13	2,361.13
Harvest Labor	8 hours	68.00	1,8889.04	1,8889.04
Wash	4 hours	34.00	9,444.52	9,444.52
Pack	2 hours	17.00	4,722.26	4,722.26
Bags & boxes	50	3.00	833.34	833.34
Deliver	0	0.00	0.00	0.00
Accounting	2 hours	17.00	4,722.26	4,722.26
Total Cost		197.00	85,444.52	54,813.72
	Cost per kg	11.00	11.00	11.00
	Total cost	197.00	54,813.72	54,813.72
Profit		19.34	5,283.42	5,283.424
% Profit of Total Revenue		9%	9%	9%

Appendix

Partial budget analysis for base income for a spearmint living mulch in an eggplant vegetable intercrop production system after establishment of the plants. Labor is calculated at $8.50/hour. Fertilizer is $10/2.5 kg. Packing supplies are $1.50/25 boxes.

Partial Budget after crop establishment				
		Study Data		
	Unit	Per 36 m^2	Per ha	Per year
Yield (kg)		8.57	2380.57	9,522.30
Price ($ per kg)		13.20	13.20	13.20
Total Revenue ($)		113.12	31,423.58	125,694.34
Fertilizer	250 g	1.00	277.78	1,111.12
Fertilize Labor	1 hour	8.50	2,361.13	9,444.52
Harvest Labor	4 hours	34.00	9,444.52	37,778.08
Wash Labor	2 hours	17.00	4,722.26	18,889.04
Packing Labor	1 hour	8.50	2,361.13	9,444.52
Packaging	25 boxes	1.50	416.67	1,666.68
Accounting	1 hour	8.50	2,361.13	9,444.52
Cost per kg ($)		11.00	11.00	11.00
Total cost ($)		94.27	26,186.32	104,745.28
Profit ($)		18.85	5,237.26	20,949.06
Profit of Total Revenue (%)		17%	17%	17%

Appendix

Sensitivity analysis. The best case was a increase in price. Labor is calculated at $8.50/hour. Fertilizer is $10/2.5 kg. Packing supplies are $1.50/25 boxes.

Sensitivity analysis after crop establishment

		Price	Price
Total Revenue	Per year	5% up	Down 5%
Yield	9,522.298	9,522.298	9,522.298
Price	13.20	13.86	12.54
Total Revenue($)	125,694.30	131,979.10	119,409.60
Fertilizer	1,111.12	1,111.12	1,111.12
Fertilize Labor	9,444.52	9,444.52	9,444.52
Harvest Labor	37,778.08	37,778.08	37,778.08
Wash ($)	18,889.04	18,889.04	18,889.04
Packing ($)	9,444.52	9,444.52	9,444.52
Bags & boxes	1,666.68	1,666.68	1,66.68
Accounting	9,444.52	9,444.52	9,444.52
Cost ($)	11.00	11.00	11.00
Profit	20,949.06	27,233.77	14,664.34
% Profit of Total Revenue	17%	20%	12%
Difference from expected profit ($)		6,284.717.00	-6,284.72
Profit percent difference		30%	-30%

Appendix

Sensitivity analysis. The competitive case is shown with a decrease in cost. Labor is calculated at $8.50/hour. Fertilizer is $10/2.5 kg. Packing supplies are $1.50/25 boxes.

Sensitivity analysis after crop establishment

	Established year	Cost 5% up	Cost 5% down
Yield	9,522.298	9522.298	9522.298
Price ($)	13.20	13.20	13.20
Total Revenue ($)	125,694.30	125694.30	125694.30
Fertilizer	1,111.12	1111.12	1111.12
Fertilize Labor	9,444.52	9444.52	9444.52
Harvest Labor	37,778.08	37778.08	37778.08
Washing labor	18,889.04	18889.04	18889.04
Packing labor	9,444.52	9444.52	9444.52
Bags & boxes	1,666.68	1666.68	1666.68
Accounting	9,444.52	9444.52	9444.52
Cost per (kg)	11.00	11.57	10.47
Total cost ($)	104745.3	110173	99698.46
Profit ($)	20,949.06	15521.35	25995.87
% Profit of Total Revenue	17%	12%	21%
Difference from expected profit ($)		-5427.71	5046.81
Profit percent difference		-26%	24%

Appendix

Sensitivity analysis. The worse case is shown with a decrease in price and an increase in cost. Labor is calculated at $8.50/hour. Fertilizer is $10/2.5 kg. Packing supplies are $1.50/25 boxes.

Sensitivity analysis after crop establishment

		Unit	Price Cost	Yield	Yield
Total Revenue	Total Revenue	Established year	5% down 5% up	5% up	5% down
Yield (kg)	Yield	9,522.298	9522.298	9998.415	9046.185
Price kg ($)	Price	13.20	12.54	13.20	13.20
Total Revenue ($)	Total Revenue	125,694.30	119,409.60	131,979.10	119,409.60
Fertilizer	250 g	1,111.12	1,111.12	1,111.12	1,111.12
Fertilize Labor	1 hrs	9,444.52	9,444.52	9,444.52	9,444.52
Harvest Labor	4 hrs	37,778.08	37,778.08	37,778.08	37,778.08
Wash	2 hrs	18,889.04	18,889.04	18,889.04	18,889.04
Pack	1 hr	9,444.52	9,444.52	9,444.52	9,444.52
Bags & boxes	# 25	1,666.68	1,666.68	1,666.68	1,666.68
Accounting	1 hr	9,444.52	9,444.52	9,444.52	9,444.52
Cost per kg ($)	Cost per kg	11.00	11.57	11.00	11.00
Total cost ($)	Total cost	104,745.30	110,1730	109,982.60	99,508.04
Profit ($)	Profit	20,949.06	92,36.62	21,996.51	19,901.61
% Profit of Total Revenue	% Profit of Total Revenue	17%	8%	17%	17%
Difference from expected profit ($)			-11712.40	1047.45	-1047.45
Profit percent difference			-56%	5%	-5%